Exploring Cross-Layer Dependencies in Congested Wireless Ad Hoc Networks

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SUMMARY

Crowds are often inconvenient for people participating in them. Consider for instance a group of friends participating in a city festival. Even if the friends stay close to each other, the limited visibility and the hindered mobility may make it difficult for them to stay together as a group. To make matters worse, communication through usual everyday devices such as cellphones is almost impossible. In vast crowded areas, the load on cellular networks is typically several times higher than usual. As a result, cellular communication faces serious limitations and text messages are delivered with huge delays–if at all.

Yet, a large number of people equipped with wireless devices, occupying a vast area, can potentially enable a distributed communication paradigm: ad hoc networking. Independent from any central infrastructure, ad hoc networks offer a compelling way to transport messages, hop by hop, from and to nodes participating in the network.

In this dissertation we introduce a protocol for group monitoring that relies solely on ad hoc networks and takes into account the privacy of the participants. We start with a thorough analysis of the requirements for exchanging messages in a group monitoring application. This analysis shows that in order to ensure untraceable communications, traditional end-to-end routing must be ruled out. Based on the analysis of the requirements, we propose a group monitoring protocol where nodes broadcast anonymous messages at regular, predetermined time intervals in a gossip-based fashion.

While gossip-based message propagation is instrumental for anonymous communications and copes well with nodes' mobility, it introduces a lot of redundancy. Since we expect ad hoc networks to be dense, high traffic is likely to collapse the entire message dissemination process. To prevent this, we look at a cross-layer optimization, by attempting to minimize message redundancy at the network layer and maximize channel utilization at the MAC layer.

At the network layer, we consider a well-known gossiping protocol called Gossip3 that is based on probabilistic rebroadcasting. We perform extensive experimental analysis of this protocol, simulating high network utilization in diverse network densities. The study shows that the protocol's level of redundancy is highly sensitive to the density of the network. In order to achieve minimal redundancy in the light of arbitrary network densities, we propose a novel algorithm that alleviates this shortcoming of Gossip3. Our algorithm tunes a node's rebroadcast probability based on the perceived density of the nodes. This way, the dissemination protocol can retain its optimal performance irrespectively of the density of the network it operates in.

At the MAC layer, we choose the CSMA protocol with binary exponential back-off (BEB), because it is simple and robust and deals well with dynamic networks. This protocol has two main parameters, namely the size of the contention window and the rate at which the contention window increases at each back-off. We perform a broad study of the performance of various CSMA-BEB parameter values for a number of network densities and node distributions. To evaluate the MAC performance in isolation from the network layer we emulate synthetic traffic. We observe the impact of the CSMA-BEB parameters with respect to goodput, fairness and latency. While the contention window increase rate has a certain impact on fairness, the contention window size is crucial for all three metrics we used. Finally, we identify the optimal parameters for a number of network densities.

To demonstrate the effectiveness of a cross-layer approach we consider both MAC and network layer in a set of experiments with realistic traffic– all nodes send new messages at regular time intervals. We show that a good cross-layer configuration allows nodes to send more messages per time unit while maintaining a high average delivery ratio (i.e., coverage) per message. Moreover, we demonstrate the interplay between the MAC and the network layer under congestion: a poorly performing MAC leads to a high number of collisions, which in turn induces the gossip protocol to forward messages more aggressively. This, ultimately, results in higher traffic at the MAC layer. Finally, an important point that emerges from these experiments is that when it comes to choosing configuration parameters at the two layers, trade-offs are often necessary. For example, a slightly lower dissemination coverage can provide a much faster message dissemination and vice versa.

In conclusion, this dissertation presents the first comprehensive study towards private ad hoc communication in the crowd. It gives an overview of principal challenges from the application level down to the MAC level. In particular, the broad study of the parameters of the MAC and network layer provides an understanding of the influence they have on each other and of the trade-offs with respect to their parameters. We finally show that cross-layer optimizations can significantly improve the overall performance of group communications.